LA-UR-20-22978
Approved for public release; distribution is unlimited.

Title: Heavy Flavor and jet studies for the future Electron Ion Collider

Author(s): Li, Xuan

Intended for: APS April meeting 2020, 2020-04-18/2020-04-21 (Washington, District Of Columbia, United States)

Issued: 2020-04-20 (rev.1)

Los Alamos
NATIONAL LABORATORY
EST. 1943

LA-UR-20-22978

Heavy Flavor and jet studies for the future Electron Ion Collider

Xuan Li (xuanli@lanl.gov)

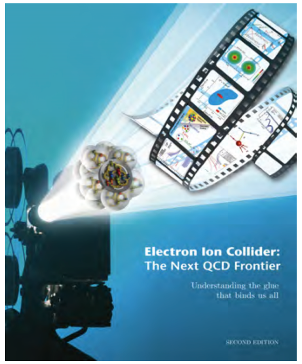
on behalf of Los Alamos National Laboratory

Outline

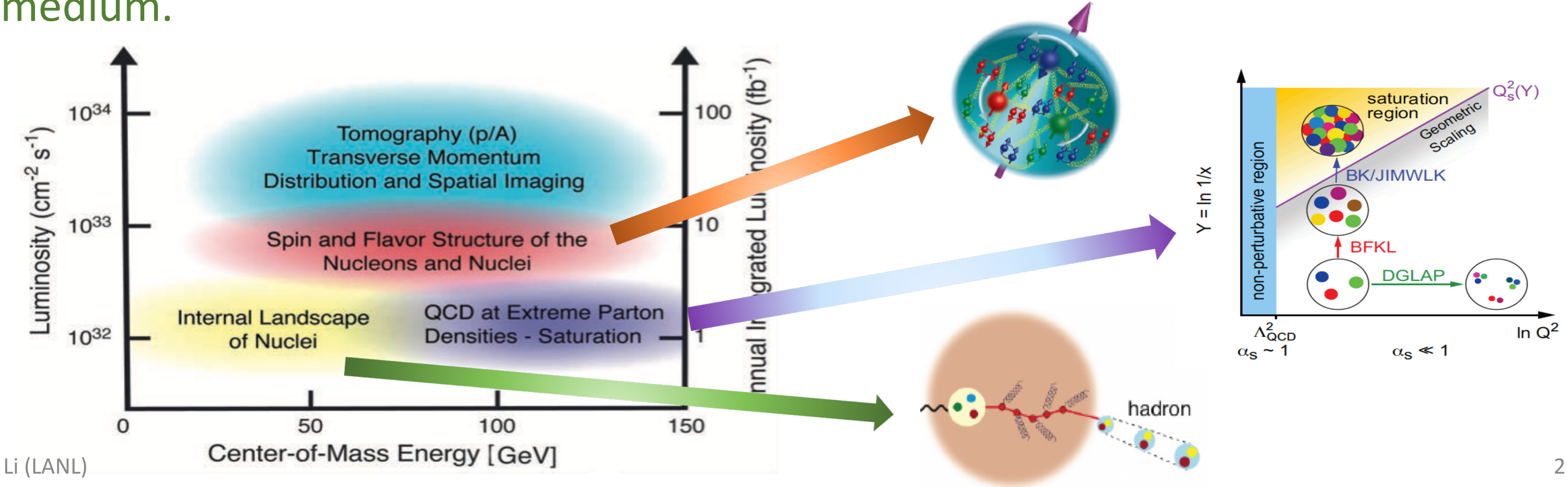
- Motivation.
- Initial detector design and tracking performance.
- Open heavy flavor studies in simulation.
- Summary and outlook.

New QCD frontier: the Electron Ion Collider (EIC)

- EIC can help solve different fundamental physics problems in a wide x and Q^2 kinematic region.
  - How quarks and gluons distributed in momentum and space within the nucleon and a heavy nuclei?
  - Proton spin origin?
  - What happens to the gluon density in nuclei, does it saturate at high energy?
  - A clean environment to study the flavor dependent energy loss in nuclear medium.



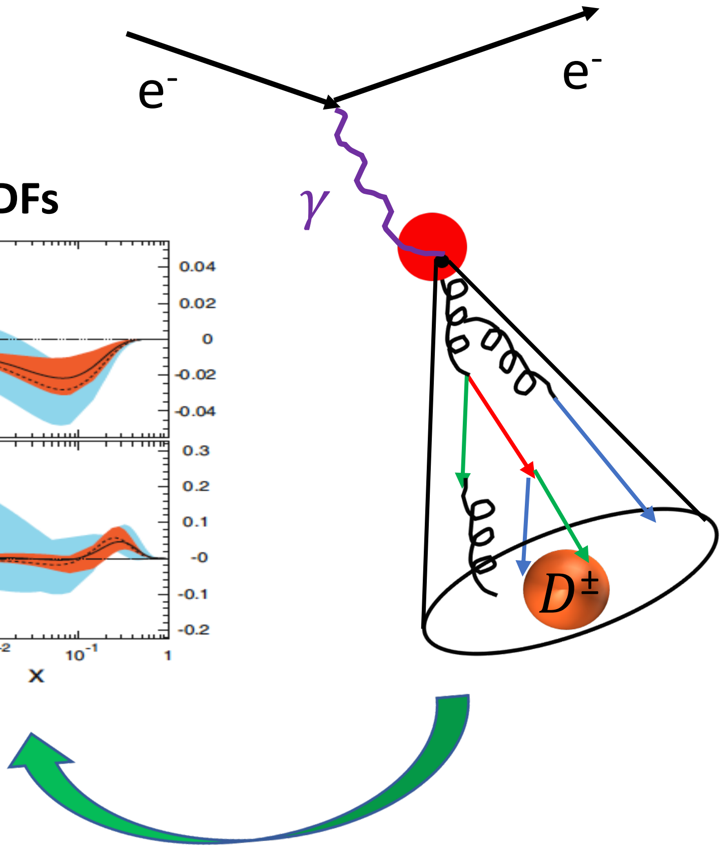
A. Accardi et al, **Eur. Phy. J. A**, 52 9 (2016).



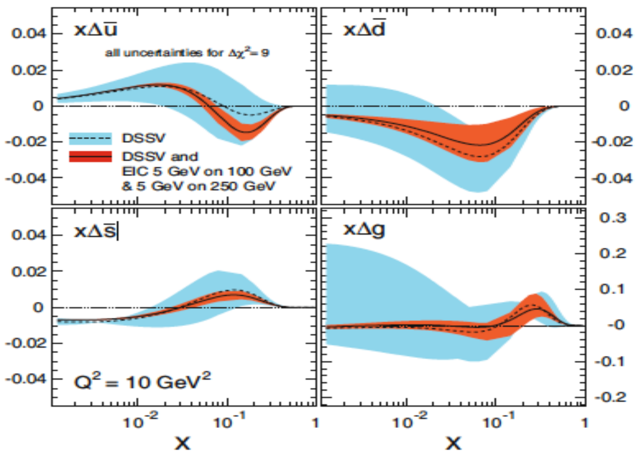
New EIC heavy flavor and jet program proposed by LANL (I)

- Through measuring heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

$$e^- + \mathrm{p} \rightarrow e^- + jet(D^{\pm}) + X$$



polarized PDFs



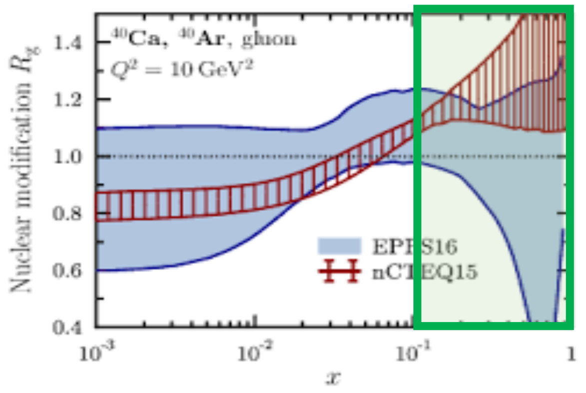
arXiv:1610.08536 **Phys. Rev. D 96, 114005 (2017)**

- To precisely determine the initial quark/gluon distribution functions in the poorly constrained kinematic region.
- To precisely study the quark/gluon fragmentation/hadronization processes.
- To provide further information on the gluon Sivers function and other spin observables.

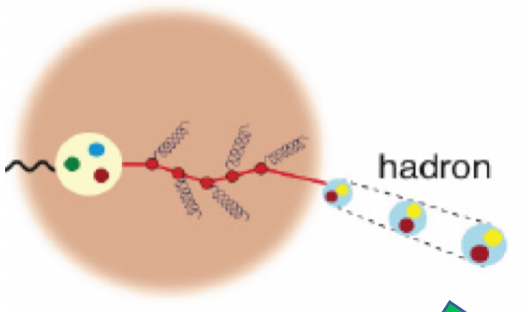
New EIC heavy flavor and jet program proposed by LANL (II)

- Through measuring heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

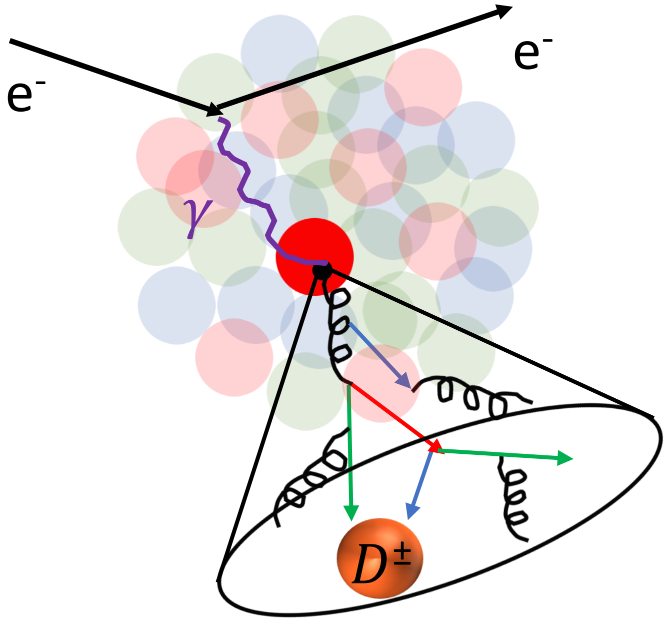
nPDF modification



Parton energy loss



$e^- + \mathrm{Au} \rightarrow e^- + jet(D^{\pm}) + X$

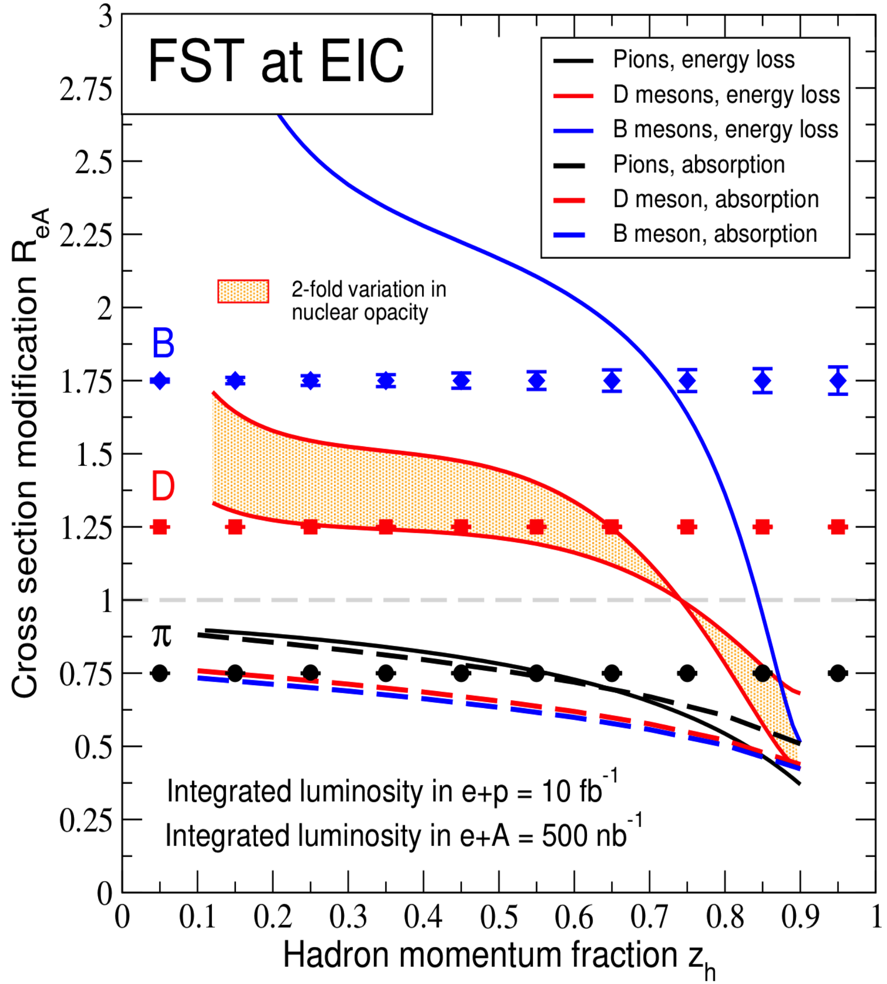


- To understand the nuclear medium effects on hadron production such as modification on nuclear PDFs, parton energy loss mechanisms and hadronization processes through the comparison of measured hadron/jet cross section between e+p and e+A collisions.

New EIC physics observables are under study

- Competing models of nuclear modification in DIS reactions with nuclei (e.g HERMES data). Differentiation not possible with light hadrons.
  - Hadronization inside nuclear matter (dashed lines).
  - Energy loss of partons, hadronization outside the nuclear matter (solid lines).
- Heavy mesons have very different fragmentation functions and formation times
  - Easy to discriminate between larger suppression for D/B mesons (in-medium hadronization) and strong/intermediate z enhancement (E-loss).
  - Enhanced sensitivity to the transport properties of nuclei.
- A Forward Silicon Tracking (FST) detector is needed at the future EIC to carry out such measurements.

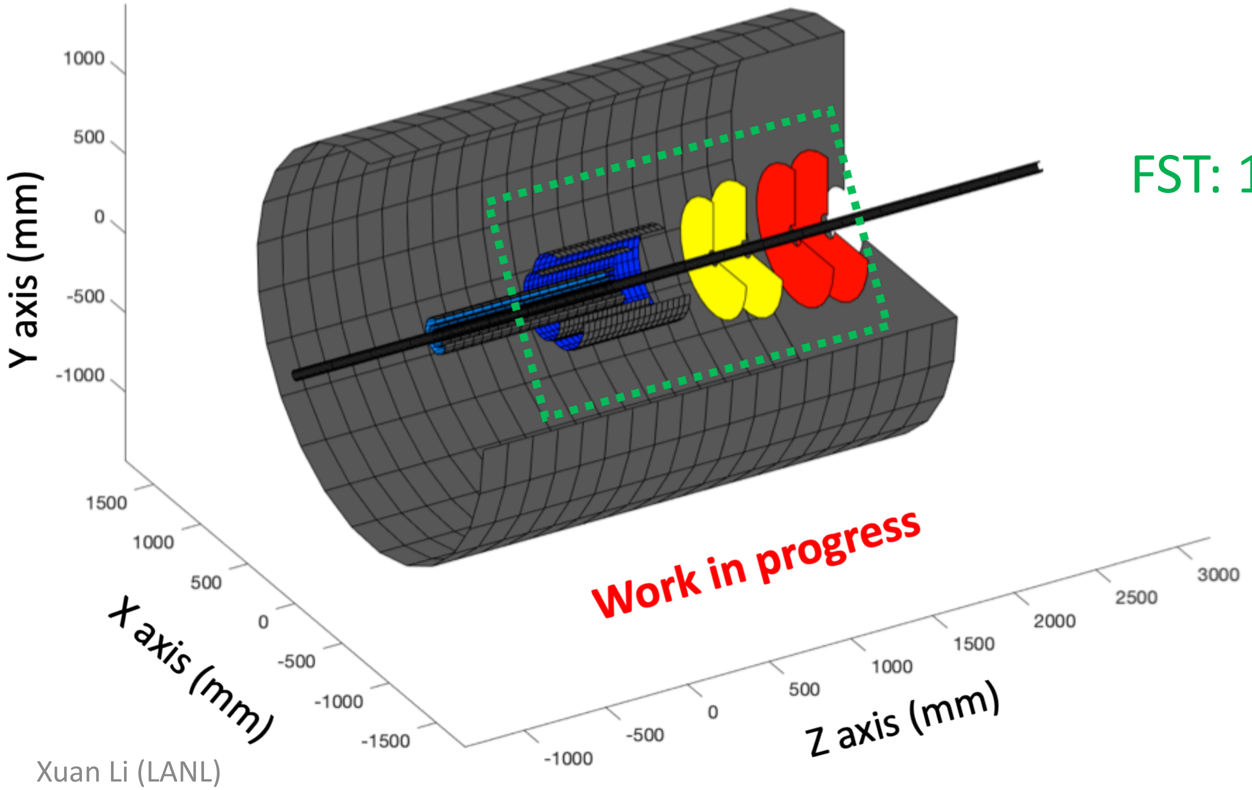
arXiv:2002.05880



Projected stat. uncertainties at event generation level and include evaluated sampling efficiencies.

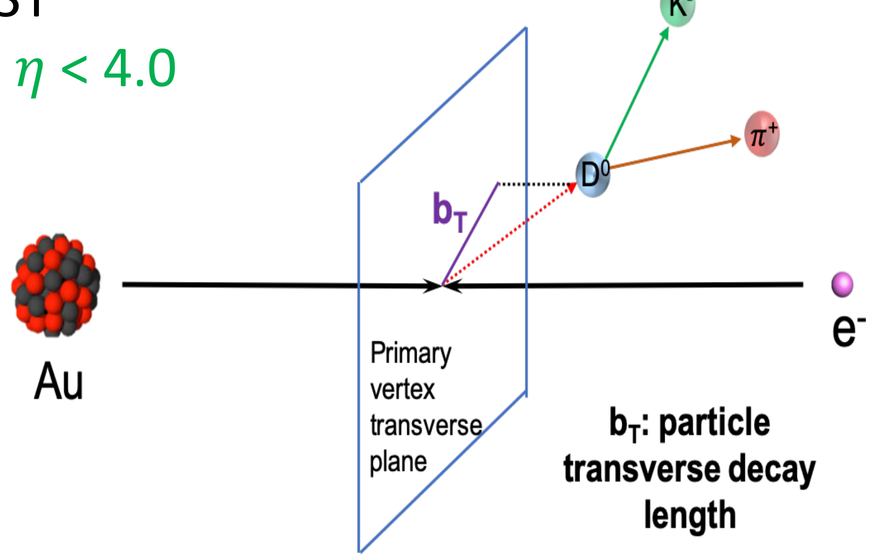
Initial design of the proposed Forward Silicon Tracking detector

- Initial detector design in fast simulation:
  - Assumed mid-rapidity silicon vertex detector with 3 barrel layers of Monolithic Active Pixel Sensor (MAPS) type sensors.
  - Forward-rapidity silicon tracking detector (FST): 2 barrel layers of MAPS silicon detector and 4 forward planes of MAPS + other silicon detector.



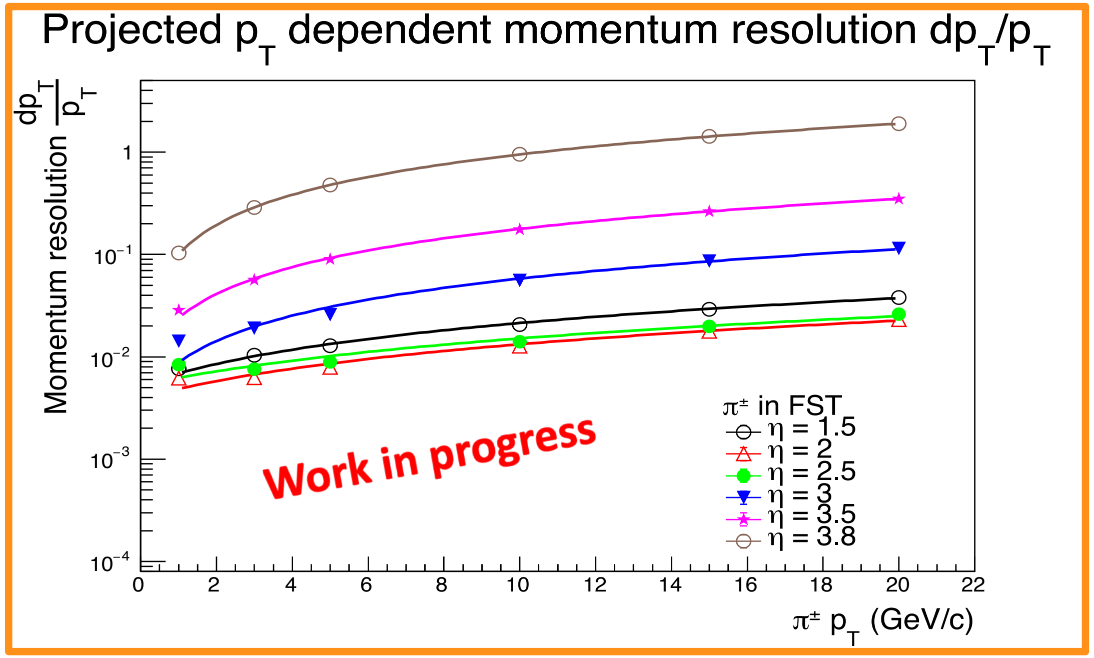
B = 3T

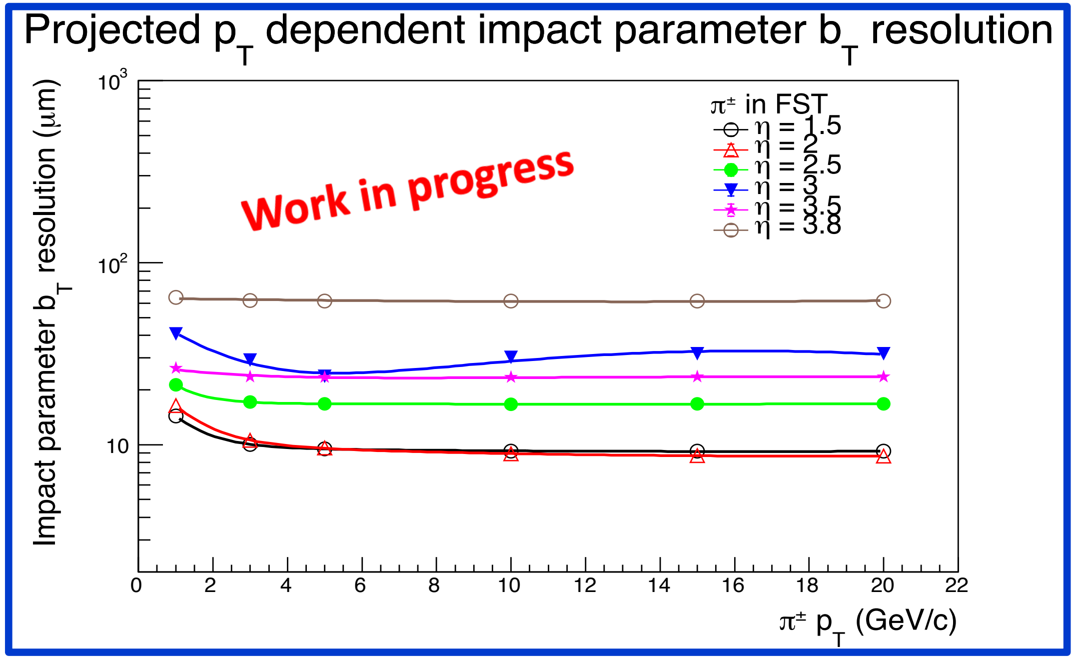
FST: $1.0 < \eta < 4.0$



Tracking performance of the proposed FST

- Evaluated track performance of the FST with pixel pitch 30 μm, material budgets per detector layer: 0.3%X_0 and the readout rate is at 500 kHz :

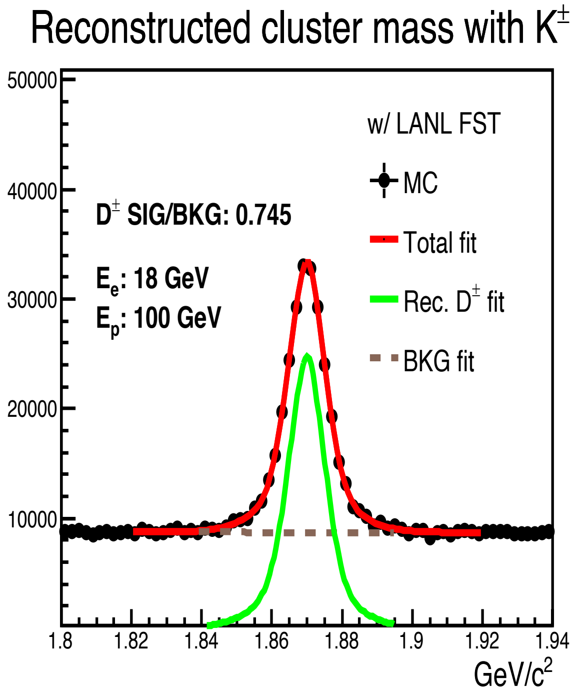


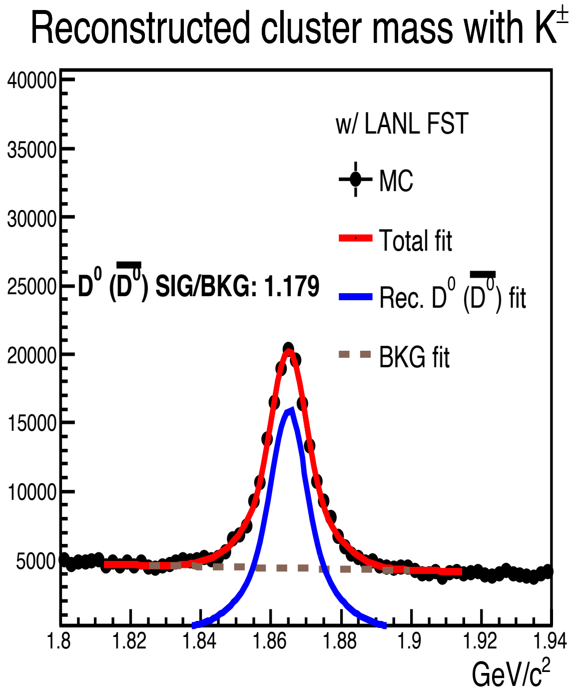


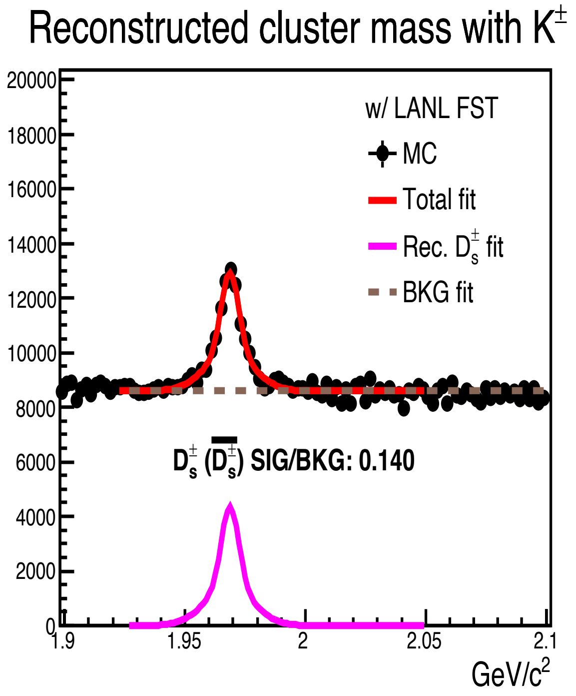
- Better than 70 μm resolution can be achieved by the initial FST design for the transverse decay length b_T measurements for tracks with p_T > 1 GeV/c over the 1.5<η<3.5 region.
- The momentum resolution dp_T/p_T are better than or consistent with the forward tracking requirements from the EIC detector handbook.

Reconstructed D mesons with the proposed FST in simulation

- The full analysis framework which includes the event generation (PYTHIA8), detector response in fast simulation, beam remnant interaction background embedding, and hadron reconstruction have been setup.
- Mass distributions of clusters with track transverse decay length matching between charged tracks with smeared tracking performance on momentum/spatial resolutions with integrated luminosity: 10 fb^{-1}.



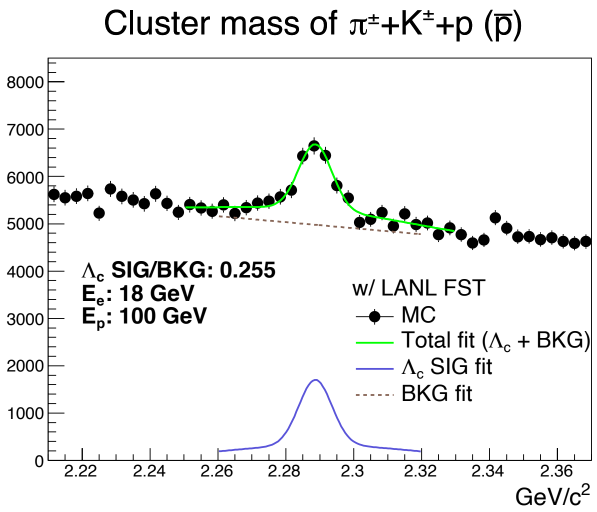


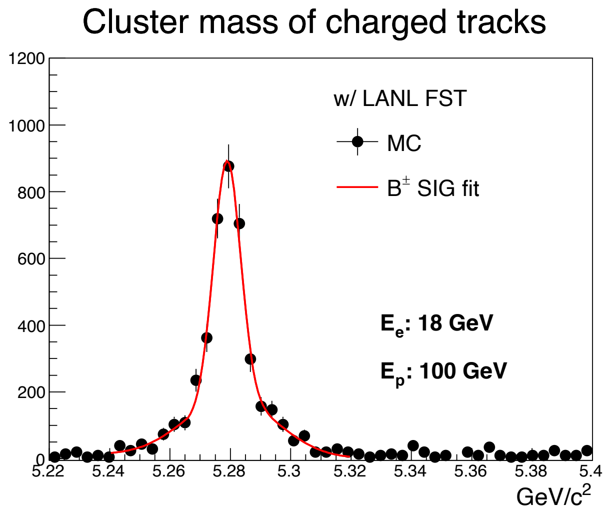


- Track $\eta: 0.5\ to\ 4$
- Tracking efficiency set at 95%.
- The performances are based on 100% $K/\pi/p$ separation.

Flavor dependent nuclear modification factor projections for reconstructed hadrons

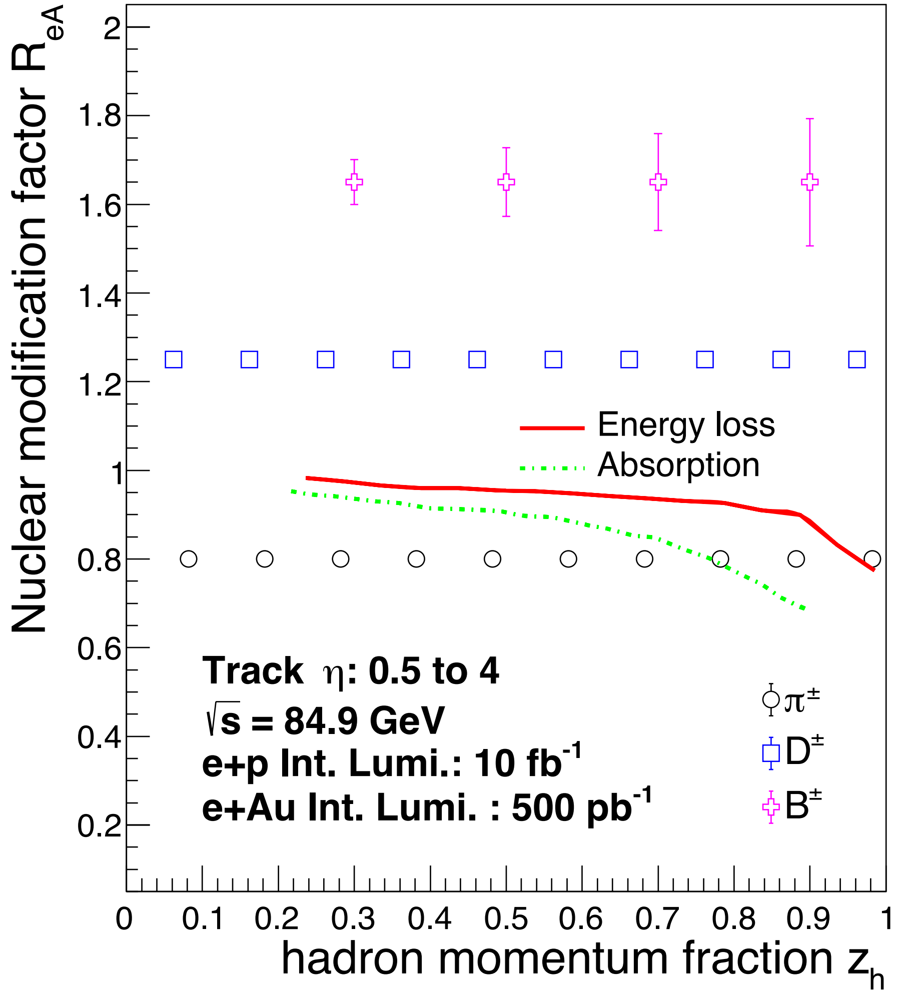
- Reconstructed other heavy flavor hadrons with the help of the proposed FST, e.g. $\Lambda_c^{\pm}$, $B^{\pm}$.





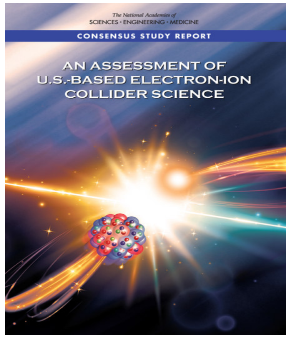
- The statistical precision of reconstructed hadrons can help separate different models of the nuclear modification on hadronization processes.
- Heavy flavor measurements at the EIC will enhance the sensitivity of the nuclear transport properties.

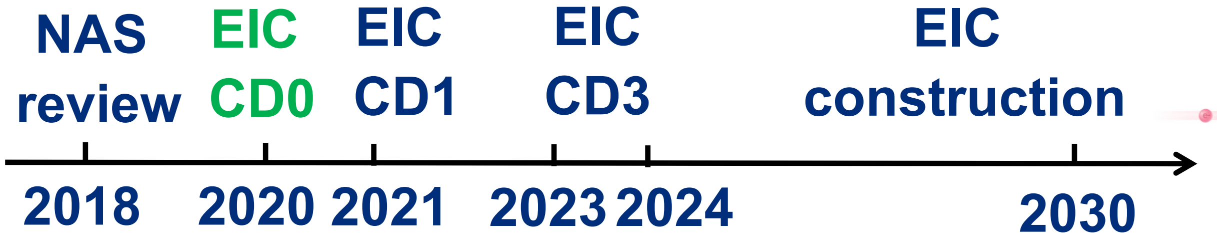
Projected hadron RAA vs z_h

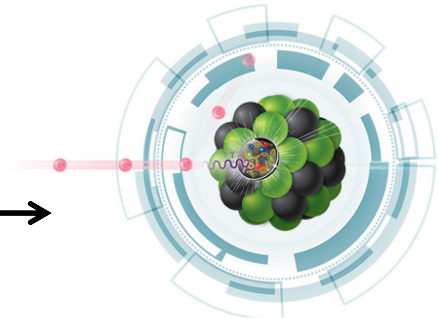


Summary and Outlook

- The new heavy flavor and jet program for the EIC will shed light into the flavor dependent energy loss and parton fragmentation processes in the poorly constrained kinematic region.
- Ongoing detector and physics simulation studies will provide guidance on the detector requirements.
- Ongoing EIC detector R&D and detector design will provide realistic detector performance parameters for the simulation studies.
- We look forward to work with more collaborators and contribute to the EIC realization.







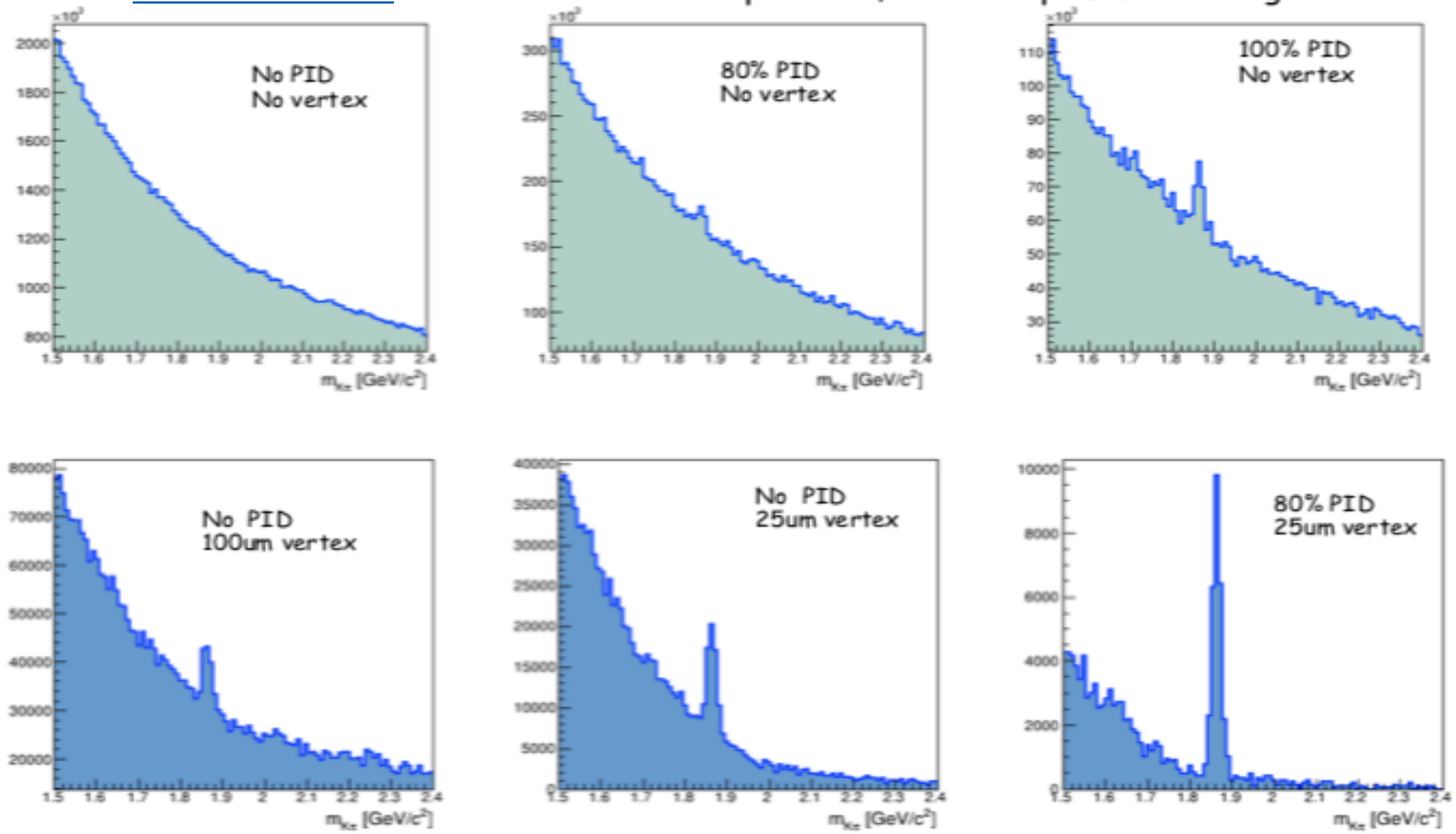
Backup

Physics performance on detector reference

- Early simulation work done by JLab colleagues on D^0 meson reconstruction with different detector systems.

arXiv:1610.08536

$D^0 \rightarrow \pi K$ mass spectrum, on the top of DIS background



EIC detector performance requirements

- From the EIC detector handbook.

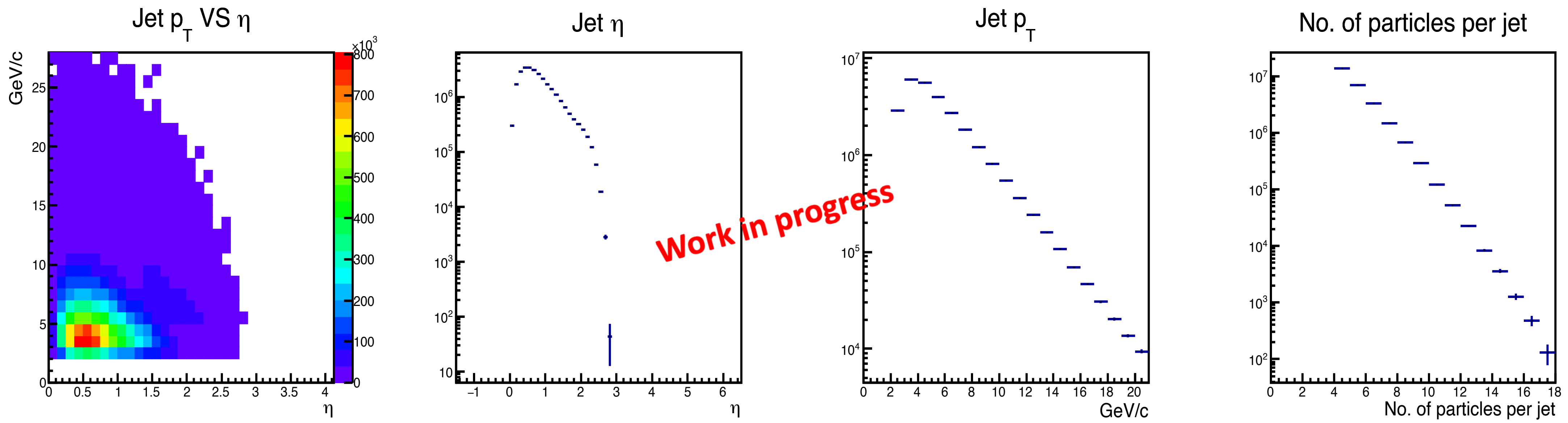
EIC Detector Requirements

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
...												
-4.5 — -4.0			Instrumentation to separate charged particles from photons				$2\%/\sqrt{E}$					
-4.0 — -3.5												
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\% \times p + 2.0\%$	~5% or less	TBD		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3σ	~50%/$\sqrt{E}$	
-3.0 — -2.5												
-2.5 — -2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$								
-2.0 — -1.5							$7\%/\sqrt{E}$					
-1.5 — -1.0												
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV μm + 5 μm	(10-12)%/$\sqrt{E}$		≤ 5 GeV/c		TBD	TBD
-0.5 — 0.0												
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/$\sqrt{E}$	
1.5 — 2.0												
2.0 — 2.5									≤ 20 GeV/c			
2.5 — 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$								
3.0 — 3.5									≤ 45 GeV/c			
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 — 4.5												
...												
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

Table 2: Physics requirements for a an EIC detector

LANL EIC program progress – inclusive jet simulation

- Moreover, the FST enables the flavor tagged jet and jet substructure studies at forward rapidity for the EIC.
- Initial look into the kinematics of inclusive jets in e+p collisions:



PYTHIA8 MC
E_e = 18 GeV
E_p = 100 GeV
$0.0 < \eta < 4.5$
Anti-kT algorithm
R = 1.0
Int. Luminosity: 10 fb^{-1}

- Jet flavor tagging study is under way.